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Field study on the impact of nocturnal road traffic noise on sleep: The importance of in- and outdoor noise assessment, the bedroom location and nighttime noise disturbances

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HIGHLIGHTS

- We studied the impact of nocturnal road traffic noise on sleep and well-being
- We used in- and outdoor noise assessment, sleep logs, actigraphy and questionnaires
- Noise exposed subjects reported an overall discomfort due to traffic noise.
- Reported noise disturbances and sleep were related; SOL and SQ being affected
- Clear and characteristic noise patterns for a noise and quiet region were found

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ABSTRACT

The aim of this field study is to gain more insight into the way nocturnal road traffic noise impacts the sleep of inhabitants living in noisy regions, by taking into account several modifying variables. Participants were tested during five consecutive nights in their homes and comparisons between effective indoor and outdoor noise levels (L_{Aeq}, L_{Amax}, number of noise events), sleep (actigraphy and sleep logs) and aspects of well-being (questionnaires) were made. Also, we investigated into what extent nocturnal noise exposure – objectively measured as well as perceived – directly relates to sleep outcomes and how the bedroom location influenced our measurements.

We found that subjects living and sleeping in noisy regions correctly perceive their environment in terms of noise exposure and reported an overall discomfort due to traffic noise. In the evaluation of the objective noise levels, the inside noise levels did not follow the outside noise levels, though the different noise patterns could be described as characteristic for a noise and quiet environment. The impact on sleep, however, was only modest and we did not find any influence of noise intrusion on mood or pre-sleep arousal levels. Concerning the subjectively reported noise disturbances during the night, a clear relationship between noise and sleep outcomes could be established; with sleep onset latencies and judged sleep quality being particularly affected.

The importance of inside and outside noise assessment as well as the use of multiple noise indicators in a home environment is further described. Additional emphasis is put on the determination of quiet control regions and the bedroom location, as this can alter noise levels and sleep outcomes. Also, including subjective noise evaluations during the night might not only provide crucial information on how participants experience the noise, but also allows for a more qualitative interpretation of the actual noise situation.

1. Introduction

Among the various noise sources, transportation noise during the night can be categorized as the most disturbing for sleep and recuperation (Muzet, 2007; World Health Organization—WHO, 2011). The effects of nocturnal road traffic noise on sleep have been extensively studied during the last decades. In laboratory studies, specific attention was paid on the establishment of dose–effect relationships and more recently, on the different sleep disturbing effects following single and combined traffic noise exposure (Basner et al., 2011; Eberhardt et al., 1987; Öhrström and Rylander, 1990). Results of large-scale field studies investigating the effects of road traffic noise on sleep using questionnaires and sleep logs tend to point in the same direction; that is, a worsening of sleep and a decreased general well-being in regions with

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increased nocturnal traffic noise (Belojević et al., 1997; Jakovljević et al., 2006; Öhrström, 1991, 2004a; Öhrström and Skånberg, 2004; Stošić et al., 2009; Van Renterghem and Botteldooren, 2012). Some studies investigated sleep disturbances together with daytime functioning and observed an overall mood deterioration – mostly in the morning – in noise exposed persons as well as psychological and somatic disturbances such as fatigue, nervousness or headaches (Belojević et al., 1997; Öhrström, 1989, 2004b).

In large-scale field studies, data of representative population samples can be collected, in this way enhancing the validity of the outcome measures. However, as individual inside noise levels are very difficult to collect in such large samples, noise evaluation relies on outside measurements and calculations. In their review of non-auditory effects of noise on health, Stansfeld and Matheson (2003) pointed out that a low association between outdoor noise levels and sleep disturbances exists. The lack of precise individual inside noise levels in home studies is a well-known shortcoming and despite this, only scarce information on such measurements and its relationship with sleep is available in the literature (Griefahn and Gros, 1986; Passchier-Vermeer et al., 2007; Pirrera et al., 2011; Tulen et al., 1986; Vallet et al., 1983). Other studies did not find any relation between objective noise levels and sleep outcomes (Griefahn et al., 2000; Nivison and Endresen, 1993).

Furthermore, in exploring a relationship between noise and sleep, it has been amply demonstrated that the degree of noise exposure is not the only factor impacting sleep. Numerous acoustical and non-acoustical factors, such as noise sensitivity or bedroom orientation, do play an important role in the determination of noise induced sleep disturbances in the home situation (Bluhm et al., 2004; de Kluizenaar et al., 2013; Marks and Griefahn, 2007; Paunović et al., 2009; Urban and Máca, 2013; Van Renterghem and Botteldooren, 2012; Welch et al., 2013). Also, information on how the noise is perceived during the night can contribute to a better understanding of the noise–sleep relationship (Murphy and King, 2014). The subjective experience of the noise exposure or disturbance is usually translated through the concept of annoyance. Noise annoyance reactions, whether occurring during daytime or nighttime, are considered to be stress reactions, as they include different affective, psychological and physiological components (Dratva et al., 2010; Guski et al., 1999; Ouis, 2002). A number of studies found a close relationship between the degree of nighttime noise annoyance caused by road traffic and poor sleep (Fyhri and Aasvang, 2010; Jakovljević et al., 2006; Öhrström, 1991, 1993; Van Renterghem and Botteldooren, 2012).

All these findings stress the importance of exploring different pathways in the assessment of road traffic noise and its influence on sleep in a home environment. The aim of this study is to gain more insight into the way nocturnal road traffic noise impacts the sleep of inhabitants living in noisy regions. To this end, we compared the effective indoor and outdoor noise levels during the night, sleep and mood between inhabitants of noisy and quiet regions in the Brussels-Capital Region. How does the objectively measured and perceived noise, as well as the other variables, differ in both groups, and how concordant are these different measurements in each group? Also, we investigated into what extent nocturnal noise exposure – objectively measured as well as perceived – directly relates to sleep outcomes and how the location of the bedroom influenced our measurements.

2. Method

2.1. Procedure and material

2.1.1. Selection of the locations and study population

Subjects living in noisy regions, or the so-called "black spots", were recruited by mail. These "black spots" are defined by the Brussels Institute for Management of the Environment (BIME; www.leefmilieubrussel.be) as "Residential or building areas with either a concentration of various types of noise pollution, or a high number of complaints concerning noise pollution." An additional screening of these areas was performed in order to avoid a maximum of confounding variables, such as noises from pubs, restaurants and others. Approximately 1050 letters were sent out, and from the 40 responses we received, 24 subjects fulfilled all inclusion & exclusion criteria and agreed to participate. The same procedure was applied for the recruitment of subjects living in quiet regions of Brussels (www.leefmilieubrussel.be), where 1400 letters were distributed. Here as well, a very low response rate was observed, which was expected, considering the high demands towards the participants. Out of the 21 reactions we received, 11 persons fulfilled all criteria and agreed to participate. Additionally, other recruitment channels, for example the newsletter of the Brussels' University, were used. This led to the enrollment of another 13 persons. In total, the quiet group consisted of 24 subjects. One participant in the noise group and two participants in the quiet group were removed from the study sample; both because of noise and sleep issues.

Inclusion and exclusion criteria were a regular sleep–wake schedule, a good general health, no children under 10 years of age, no shift or night work, no pregnancy, an alcohol usage not exceeding 15 consumptions a week, no medication that alters sleep (antidepressants, hypnotics, tranquillizers), having a professional activity in the Brussels-Capital Region and living in a noisy or quiet region for at least one year.

For the noise group, 23 subjects fulfilled all criteria and were included in this study (average age of 42 years; ages between 22 and 62; 15 females, 8 males). The quiet group consisted of 22 subjects, with an average age of 42 years (ages between 23 and 64; 15 females, 7 males). The averaged length of residence for the noise and the quiet group did not statistically differ [respectively 5.6 and 9.5 years; $U = 150$; non-significant (ns)].

69% of the studied locations in the noise group were apartments (1st–7th floor), 26% were enclosed houses and 4% were semi-detached houses. 82% of the bedrooms had double-glazed windows and faced the roadside in 39% of the cases. For the quiet group, 32% of the studied locations were apartments (1st–7th floor), 45% were enclosed houses, 13% were semi-detached houses and 9% detached houses. 85% of the bedrooms had double-glazed windows and faced the roadside in 54% of the cases.

2.1.2. Assessment of nocturnal road traffic noise

Traffic noise was recorded inside and outside each bedroom place during seven consecutive nights using an Integrator Class 1 (inside) and Class 2 (outside) Sound Level Meter (SLM; Metravib®). The measurement range was 20–137 dB(A) for Class 1 and 30–137 dB(A) for Class 2 SLM. The outside sound level meter was set up at the outside façade of each bedroom. The microphone was attached at a distance of ± 0.5 m from the window, using balconies or other possibilities and taking into account safety measures for possible vandalism and robbery. Indoor noise was recorded inside each bedroom, near the head of the bed where possible, according to the accessibility to a power supply.

An averaged noise level value per 30-second epoch was recorded from 10 P.M. to 08 A.M. during seven consecutive nights. Noise data was analyzed with the software program dBTrait (version 4.805).

For the subjective evaluation of traffic noise disturbances during the night, subjects completed a visual analog scale (VAS) every morning. They were asked to rate, using a 100 mm line from 0 to 10, into what extent they were disturbed by noise during the night. Additionally, they completed open questions on the sources and the frequency of occurrence of the noises.

2.1.3. Assessment of sleep

Actigraphic recordings, type Sensewear Armband Pro2 from Bodymedia Inc. Sensewear®, were made during seven consecutive nights. Analyses were performed with Innerview Professional 5.0. software and derived sleep variables were: Time in Bed (TIB: lying down period), Sleep Onset Latency (SOL: calculated from the start of the TIB period to the first consecutive three minutes of sleep scoring), Wake

after Sleep Onset (WASO: total time scored as awake after sleep onset across the TIB period), Total Sleep Time (TST: sum of time scored as sleep during the TIB period) and Sleep Efficiency (SE: percentage of TST over TIB). The actigraphic devices recorded epochs of 30 s or 1 min.

Subjects completed a sleep log every morning for seven days. Questions included time to go to bed, time of lights-off, estimated sleep onset latency, number and reason for awakenings during the night, time of wake up and subjective sleep quality (on a scale ranging from 1 = very bad sleep; 2 = rather poor; 3 = reasonably well; 4 = slept very well). The derived sleep variables were Time in Bed (TIB: from lights-off till wake-up), Sleep Onset Latency (SOL), number of awakenings and sleep quality (SQ). The average times of lights-off and wake up were respectively 23 h49 and 6 h54 for the noise group and 23 h32 and 7 h08 for the quiet group.

2.1.4. Daily and general questionnaires

In addition to the VAS and the sleep log, subjects also completed the Pre-Sleep Arousal Scale (PSAS; 16-item questionnaire assessing the degree of somatic and cognitive complaints when falling asleep; Nicassio et al., 1985) and the Stanford Sleepiness Scale (SSS; degree of sleepiness in the morning; Hoddes et al., 1973) every morning.

Mood was evaluated with the short version of the Profile of Mood States (POMS; Curran et al., 1995) in the morning as well as the evening. The POMS consisted of 32 adjectives describing mood states which are grouped into five subscales (Anger, Fatigue, Vigor, Depression and Tension).

The general questionnaires included the Pittsburgh Sleep Quality Index (PSQI; Buysse et al., 1989) and the Epworth Sleepiness Scale (ESS; Johns, 1991) as a measure of respectively general sleep quality and daytime sleepiness. Also, a questionnaire adapted from Öhrström (2004b) consisting of seven questions on living environment and satisfaction was administered. In this questionnaire, we informed on the type of residence (response category: detached, semi-detached, enclosed house or apartment with mention of level) and the length of residence. The position of the living room and bedroom (facing the road side with a response category of "yes" or "no") and the type of window (single or double glazed windows) were asked. Questions on the degree of satisfaction of the house and of the living environment were included with a response category for each question ranging from "not satisfied", "rather satisfied", "satisfied" to "very satisfied". Furthermore, it was asked whether people felt disturbed in their daily activities due to road traffic noise ("yes" or "no") within a second step specifically referring the following indoor activities: conversation, difficulties in concentration, difficulties in falling asleep, rest/relaxation, awakenings during night and the possibility of opening the windows. Detailed questions on disturbances of outdoor activities concerned conversation and rest/relaxation outside. All questions on the disturbance of indoor and outdoor activities could be answered with a "yes" or "no". Finally, the degree of noise sensitivity was evaluated using response categories ranging from "not at all sensitive", "not very sensitive", "rather sensitive" to "very sensitive".

Data collection of the noise group took place from 9/2006 till 5/2007 and for the quiet group, from 3/2008 till 6/2009. Holiday periods were excluded due to the diminished road traffic volume (i.e. July/August, second half of December and Easter holiday). Both groups were tested over comparable time periods, so to equally approximate different weather conditions in each group (Tworoger et al., 2005; Kohsaka et al., 1992). We only included weekdays in the analyses as sleep patterns were altered during the weekend (from Sunday evening to Friday evening; Monday refers to the night from Sunday to Monday and accordingly for the rest of the weekdays).

This study was approved by the Ethics Committee of the University of Brussels. All participants were fully informed of the research purposes and completed an informed consent form before the start of the test period. At the end of the test week, they received four movie tickets as compensation.

2.2. Analyses and statistical design

2.2.1. Noise analyses

Results from previous analyses (Pirrera et al., 2011) showed that a timeframe for assessing traffic noise based on the time subjects actually spent in their bed did approximate most closely the actual noise exposure during sleep. Consequently, we assessed nocturnal road traffic noise using a timeframe equaling the TIB period (i.e. time in bed period from "lights-off" until "wake up", as derived from the sleep logs).

The noise indicators $L_{Aeq(TIB)}$ and $L_{Amax(TIB)}$ of the inside and outside measurements were calculated for the noise and the quiet group. For the analyses of noise events, we used the noise event categorization in accordance with the sleep disturbances and health effects observed in the population, as described by the World Health Organization WHO (2009).

- Range 1: noise events from 30 dB(A) to 40 dB(A). Increase of primary sleep disturbances.
- Range 2: noise events from 40 dB(A) to 55 dB(A). Increase in adverse health effects in a large part of the exposed population.
- Range 3: noise events above 55 dB(A). Adverse health effects occur frequently.

With a measurement period ranging from 10 P.M. to 8 A.M., we could not sample the complete period of TIB in all subjects. In 2.2% of the registered nights, subjects went to bed before 10 P.M. and in 9.5% of the nights, subjects were still in bed after 8 A.M. After 8.30 A.M. this percentage was reduced to 4.5%.

2.2.2. Statistical design

All dependent variables were screened for extreme outliers, defined as the average value ± 3 standard deviations. As almost no effects of "day of the week" were found, we used the average week values for the analyses.

The noise indicators $L_{Aeq(TIB)}$, $L_{Amax(TIB)}$ and noise events inside and outside the bedrooms of the noise and the quiet group were compared with non-parametric Mann–Whitney *U* tests (*U*). The same test was also used for the comparison of the sleep variables obtained with actigraphy; TIB, SOL and the number of awakenings from the sleep logs, as well as the results from the daily and general questionnaires. A Chi-square test was used to compare the SQ assessed with the sleep log, the VAS and the results of the questionnaire on living environment and satisfaction.

Spearman correlation tests were used to gain insight into how noise and sleep are related. First, a relationship between the objectively measured inside noise levels (three noise indicators) and sleep was assessed. Specifically, for the relationship between the sleep variable SOL and noise, we calculated the noise exposure from the first 90 min after the "lights-off" time mentioned in the sleep logs. Second, a relationship between the perceived noise disturbances during the night and sleep was investigated.

A *p*-value of 0.05 was set as a threshold for statistical significance. Analyses were performed with the statistical software program Statistica version 9.0.

3. Results

3.1. Comparison between the noise and the quiet group

3.1.1. Noise assessment

Table 1 represents the averaged values of the inside and outside noise levels in L_{Aeq}, L_{Amax} and number of noise events in the noise and the quiet group. Regarding the L_{Aeq} noise indicator, a significant difference was found between both groups for the outside noise levels but not for the inside noise levels. L_{Amax} values outside were increased in the noise group, but did not reach a level of significance. This was the case for the inside L_{Amax} levels, with a significant increase in the quiet

Table 1
Averaged weekly indoor and outdoor noise levels for all noise indicators in the noise (N) and quiet group (Q): average, range and significance level.

	Noise group		Quiet group		p-level	
Noise indicator	Outside	Inside	Outside	Inside	Outside (N-Q)	Inside (N-Q)
$L_{Aeq(TIB)}$	61.5 dBA *(36.5–69.5 dBA)*	38.5 dBA *(28.9–45.7 dBA)*	51.2 dBA *(43.3–58.7 dBA)*	37.4 dBA *(28.0–46.4 dBA)*	.04*	.53
$L_{Amax(TIB)}$	80.6 dBA *(55.9–91.8 dBA)*	56.7 dBA *(42.5–63.1 dBA)*	71.7 dB(A) *(58.4–79.5 dBA)*	60.7 dBA *(49.1–69.6 dBA)*	.84	.01*
R1—30–40 dBA[a] *% of noise events*	11% *(0–60%)*	34% *(6–88%)*	39% *(0–75%)*	14.5% *(4–32%)*	.0005*	.001*
R2—40–55 dBA[a] *% of noise events*	58% *(8–98%)*	3.9% *(0.5–28%)*	51% *(22–98%)*	2.8% *(1–7%)*	.60	.47
R3—> 55 dBA[a] *% of noise events*	29% *(0.1–89%)*	–	5.7% *(1–35%)*	–	.11	–

[a] Averaged percentage of number of epochs in which noise events occurred relative to the total number of epochs over a complete night.
* p level statistically significant at .05.

group. The results of the three ranges of noise events clearly show a difference in distribution of noise events across both groups. In the noise group, more noise events of the higher ranges were present outside, which is reflected in a significant increase in lower noise events inside as compared with the quiet group. The quiet group is characterized with more noise events of the lower ranges outside as compared with the noise group. For the inside noise levels, we found more than 50% of the noise events in the highest range to be absent, so no further analyses were performed.

3.1.2. Sleep assessment

The sleep information obtained with the daily sleep logs showed large inter- and intra-individual differences. In the comparison of the sleep variables between both groups, one statistically significant difference for the TIB variable was found, with less TIB in the noise group compared with the quiet group (Table 2).

In Table 3, the sleep variables registered with actigraphy are summarized and large inter- and intra-individual differences were also noticed. One trend towards significance was found for the TIB variable, with subjects in the noise group spending less time in bed compared with the quiet group.

3.1.3. Daily and general questionnaires

The results of the questionnaire regarding the general evaluation of road traffic noise disturbances and the degree of satisfaction of one's house and living environment are summarized in Table 4. Except for the degree of satisfaction of the dwelling, all variables appeared to be statistically significantly different in the comparison between both groups, with more traffic noise disturbances and a lower satisfaction of the living environment reported in the noise group.

PSQI and ESS scores were both within the normal range and did not significantly differ between both groups (respectively averaged scores for the noise and the quiet group: 3.4 and 8.6; 4.0 and 7.7; $U = 198.5$ and $U = 203$; both ns).

Regarding the evaluation of the subjective noise sensitivity, subjects in both groups mainly appeared to be 'not really sensitive' (30.4% for the noise and 27.3% for the quiet group; $X^2(1) = .22$; ns) and 'rather sensitive' towards noise (56.5% for the noise group and 59.1% for the quiet group; $X^2(1) = .18$; ns).

In the comparison of the results of the daily questionnaires SSS, the subscales somatic and cognitive complaints of the PSAS and the POMS (morning and evening), no statistically significantly differences were found (all $p > .10$).

Table 5 represents the averaged percentages of the VAS scores evaluating noise disturbances during the night. Large inter- and intra-individual differences were noticed in the report of the noise sources. The overall score on perceived noise disturbances as well as the report of road traffic as a disturbing noise source was significantly higher in

Table 2
Weekly averaged results of the sleep variables obtained with sleep logs in the noise and the quiet group: average, range and significance level.

	Noise group	Quiet group	p-level
Time in bed (TIB), min	421 (310–564)	454 (412–528)	.03*
Sleep latency (SOL), min	18.06 (1–42)	13.03 (1–30)	.33
Awakenings/night, number	1.1 (0–4.8)	1.0 (0–2.8)	.58
Sleep quality (%)			
- Slept very well/rather good	79%	83%	.47
- Slept rather bad/very bad	21%	16%	

* p level statistically significant at .05.

Table 3
Weekly averaged results of the sleep variables obtained with actigraphy in the noise and the quiet group: average, range and significance level.

	Noise group	Quiet group	p-level
Time in bed (TIB), min	433 (307–531)	461 (389–525)	.06
Total Sleep Time (TST), min	363 (283–469)	382 (279–453)	.14
Sleep latency (SOL), min	12.5 (0–25)	11.1 (4–21)	.60
Wake After Sleep Onset (WASO), min	41 (6–97)	48 (10–96)	.42
Sleep efficiency (SE), %	84.3% (69%–93%)	83.1% (65%–92%)	.47

Table 4
Percentages of the degree of road traffic noise disturbance inside and outside the dwelling and the degree of satisfaction of the dwelling and living environment in the noise and the quiet group.

	Noise group	Quiet group	p-level
In general, do you feel disturbed by road traffic noise in your daily activities?	YES: 65.2%	YES: 13.6%	< .0001*
Disturbances inside the dwelling			
- *Conversation*	17.4%	0%	< .0001*
- *Concentration*	34.8%	4.5%	< .0001*
- *Rest/relaxation*	30.4%	4.5%	< .0001*
- *Trouble falling asleep*	17.4%	0%	< .0001*
- *Awakenings during night*	13.0%	0%	.0002*
- *Opening the windows*	78.3%	18.2%	< .0001*
Disturbances outside the dwelling			
- *Conversation*	60.9%	0%	< .0001*
- *Rest/relaxation*	56.5%	4.5%	<.0001*
Degree of satisfaction of the dwelling			
- *Very satisfied/satisfied*	82.6%	86.4%	.42
- *Rather satisfied/not satisfied*	17.4%	13.6%	
Degree of satisfaction of the living environment			
- *Very satisfied/satisfied*	60.9%	90.9%	< .0001*
- *Rather satisfied/not satisfied*	39.1%	9.1%	

* p level statistically significant at .05.

Table 5
Weekly averaged score and percentage of subjectively reported noise disturbances during the night as assessed with the VAS in the noise and the quiet group.

	Noise group	Quiet group	*p*-level
Average score/10	1.3	0.4	.02*
Noise sources			
- *Traffic noise*	14%	1%	.0005*
- *Other noise outside*	1.7%	2.8%	.65
- *Noise inside*	17.5%	13.0%	.42
- *Not specified*	13.2%	4.7%	.04*
- *No noise*	53.4%	78.6%	.0002*

* *p* level statistically significant at .05.

the noise group. Also, there was significantly less noise in general in the quiet group as compared with the noise group.

3.2. Relationship between noise exposure and sleep

In the noise group, unclear patterns of correlations were found between the actual measured inside noise levels (three noise indicators) and sleep as assessed with sleep logs and actigraphy. In the quiet group, no relationships were found between the noise levels inside (three noise indicators) and sleep.

Regarding the relationship between the subjective evaluation of noise (VAS) during the night and sleep in the noise group, a significant negative correlation was found between sleep quality (sleep log) and the VAS ($r = -.45$, $p < .05$) as well as a significant positive relation between SOL (actigraphy) and the VAS ($r = .43$, $p < .05$). A trend towards a positive significant relationship was found for the SOL (sleep logs) and the VAS ($r = .40$, $p < .10$). In the quiet group, no relationship was found between the subjective evaluation of noise and sleep.

3.3. Role of the bedroom location

In Table 6, the averaged inside and outside noise levels for all three noise indicators in the noise and the quiet group are summarized according to the bedroom location. In the noise group, the outside noise levels were statistically significantly higher for the bedrooms located at the street side compared with those located at the back side for all three noise indicators, with the exception of the lower noise ranges. Those differences were however not reflected inside the bedrooms, where no differences were found between noise levels measured at the street versus the back side of the dwellings. In the quiet group, no significant differences were found in the comparison of measurements at the street versus the backside of the house, with the exception of the outside L_{Amax} being significantly increased for the bedrooms located at the street side.

For the inside noise levels, we found more than 50% of the noise events in the highest range to be absent in both groups, so no further analyses were performed.

Regarding the subjective evaluation of noise during the night, no significant difference in the overall noise score (VAS) was found with respect to the bedroom orientation in the noise group. However, 22% of the participants sleeping at the street side in that group reported being significantly more disturbed from road traffic noise compared with 11% of the participants sleeping at the back side of their dwellings ($X^2 = 4.39$; $p < .05$). In the quiet group, 3.4% of the participants sleeping at the street side reported road traffic noise as a disturbing noise source versus no report of traffic noise for those sleeping at the back.

The location of the bedroom did not influence the results of the daily questionnaires SSS, PSAS or POMS, neither the results of the sleep variables measured with actigraphy. The SOL assessed with the daily sleep logs was significantly increased in the participants of the noise group having their bedrooms located at the street side. They had, on average, a SOL of 27 min compared to 11 min for those sleeping at the backside ($U = 23$; $p < .05$). No significant difference was found in the quiet group (11 min. for those sleeping at the street side versus 14 min. for those sleeping at the backside). A similar result was also found for the item 'difficulties falling asleep' in the general questionnaire. In the noise group, 33% of the subjects sleeping at the street side versus 7% at the back side reported difficulties falling asleep ($X^2 = 21.13$; $p < .0001$). Participants in the quiet group did not report any difficulty falling asleep in the general questionnaire (see Table 4).

4. Discussion

4.1. Comparison between the noise and the quiet group

4.1.1. Noise assessment

Overall, the averaged outside noise levels were clearly distinct and characteristic for each area, as well as comparable to noise levels measured in previous field studies (Griefahn et al., 2000; Öhrström and Skånberg, 2004; Stošić et al., 2009). Remarkably, the L_{Aeq} levels outside were not accordingly reflected inside the bedroom, where no significant difference was found between both groups. However, investigating other noise indicators such as L_{Amax} and the number of noise events allowed us to conclude that the noise distribution inside might be organized and originated in a different way for each group. In the noise group, the elevated number of inside noise events in range 1 (30 to 40 dBA) indicates t]he presence of a higher background noise level. This is most probably due to traffic noise, as the number of noise events outside in ranges 2 and 3 (40 to >55 dBA) was clearly increased. In the quiet group, a noise pattern with an overall lower background noise level inside with more peak levels is found. This increase in L_{Amax} inside might be the consequence of opening the windows during the night. As we did not let the participants report whether they slept with opened or

Table 6
Averaged weekly indoor and outdoor noise levels in L_{Aeq}, L_{Amax} and number of noise events according to the bedroom location in the noise (N) and the quiet group (Q).

Noise indicator	Noise group		Quiet group		*p*-level	
	Street side ($N = 9$)	Back side ($N = 14$)	Street side ($N = 12$)	Backside (N = 10)	Street/back (N)	Street/back (Q)
$L_{Aeq(TIB), outside}$	64.8 dBA	51.8 dBA	52.5 dBA	48.7 dBA	.002*	.24
$L_{Amax(TIB), outside}$	84.6 dBA	66.5 dBA	73.3 dBA	68.3 dBA	.004*	.01*
R1, 30–40 dBA, outside, %[a]	7.6%	13.3%	38.6%	39.9%	.19	.84
R2, 40–55 dBA, outside, %[a]	26.7%	78.1%	48.9%	54.4%	.0003*	.57
R3, >55 dBA, outside, %[a]	62.4%	8.2%	8.0%	3.1%	.002*	.30
$L_{Aeq(TIB), inside}$	37.9 dBA	38.9 dBA	38.2 dBA	36.2 dBA	.68	.40
$L_{Amax(TIB), inside}$	55.1 dBA	57.5 dBA	60.8 dBA	60.6 dBA	.68	.24
R1, 30–40 dBA, inside, %[a]	37.6%	31.7%	16.9%	13.5%	.29	.33
R2, 40–55 dBA, inside, %[a]	8.7%	4.5%	2.9%	3.3%	.21	.66

[a] Averaged percentage of number of epochs in which noise events occurred relative to the total number of epochs over a complete night.
* *p* level statistically significant at .05.

closed windows on a daily basis, we cannot fully confirm this. However, based on the results of the general questionnaire, about 78% of the participants of the noise group experienced difficulties in opening their windows during the night as a consequence of elevated traffic noise—compared with 18% of the participants in the quiet group. With an averaged outside noise level of 61.5 dB(A) during nighttime in the noise group – compared to 51.2 dB(A) in the quiet group – it seems likely that people were indeed not capable of opening their windows during the night. This might consequently have been more prevalent in the quiet group, eventually resulting in noise levels reaching on average almost equal and maximally higher values as compared to the noise group. In this context, it could have been useful to collect data on the year in which the houses and apartments were built; so additional information on acoustic insulation characteristics was available to further describe and explain the discrepancies found in our results.

Analysing the subjective evaluation of noise exposure during the night confirms the presence of higher traffic noise levels in the noise group. Based on these results, no difference in noise intrusion originating from inside sources was found between both groups. Also, participants in the noise group not only reported being more disturbed by noise during the night, but in 14% of the time, this noise intrusion was caused by traffic noise. This subjective evaluation reflects well the difference in the quality of the noise during the night in both groups as we objectified it.

In line with recent findings (Murphy and King, 2014), our results demonstrate that the sole use of an averaged sound pressure level as noise indicator in a field context is insufficient to draw conclusions with respect to noise induced sleep disturbances. The added value of incorporating subjective evaluations on night noise disturbances in noise assessment instruments is also well-demonstrated in the work of Murphy and King (2014).

4.1.2. Sleep assessment

The sleep data obtained with actigraphy showed, except for a tendency toward less time in bed in the noise group, no differences between both groups. These findings are contradictory to the results of a study performed by Öhrström and Skånberg (2004), where the noise exposed subjects spent significantly more time in bed compared to subjects sleeping in quiet regions.

Actigraphic devices are easy to use, less expensive and time-consuming instruments compared to polysomnography (PSG). Despite discrepancies in sleep–wake and wake–sleep transitions, they were found to be a valid alternative to PSG (Lockley et al., 1999; Sadeh, 2011). Other field studies investigating traffic noise induced sleep disturbances used actigraphy as well, but contradictory findings were reported. Whereas Horne et al. (1994) concluded that aircraft noise events did almost not affect the sleep of their participants, a large study on road and railway noise performed by Passchier-Vermeer et al. (2007) reported sleep deterioration with increasing noise.

Our results of the daily sleep logs showed that participants in the noise group had an overall somewhat worse sleep, and spent significantly less time in bed as compared to the participants in the quiet group. Taking into account our relatively small study sample, those differences would have been more pronounced if a larger population sample was investigated. This was the case for larger-scaled field studies, in which sleep onset latency and sleep quality were particularly impacted in noisy regions (Belojević et al., 1997; Öhrström, 1989; Stošić et al., 2009).

4.1.3. Daily and general questionnaires

The results of the general questionnaire are in line with the original work of Öhrström (2004b). Generally, subjects living in a noisy region perceive traffic noise as a source of daily discomfort which impacts their indoor as well as their outdoor activities. Although both groups were equally satisfied with their dwellings, subjects living in noisy regions were less satisfied with their living environment. The negative effect of traffic noise disturbances on residential satisfaction was also found in a recent study by Urban and Máca (2013).

But contrary to what could have been expected, the discomfort caused by traffic noise during daytime as well as nighttime as reported in the general questionnaire and the VAS, did not seem to impact mood or pre-sleep arousal levels as measured on a daily basis in the participants of the noise group. Those findings are contradictory to the results from studies in which mood was assessed over several days (Belojević et al., 1997; Öhrström, 1989, 2004b). The mood questionnaire completed in the evening did also not differ between both groups, which is in line with previous study results from Öhrström (1989).

It has been clearly demonstrated that the individual degree of noise sensitivity is a major determinant for result outcomes in noise and sleep research (Marks and Griefahn, 2007; Welch et al., 2013). In this study, neither groups differed with respect to this variable, which allows us to exclude it as a confounding variable.

4.2. Relationship between noise exposure and sleep

No clear indication of a direct impact of objectively measured noise (inside levels, three noise indicators) on sleep was found, neither for the sleep data obtained by sleep logs nor for the actigraphic measurements in both groups. Similar results were found in the study performed by Griefahn et al. (2000) but contradictory to the results of a large cohort study in Switzerland, in which road traffic noise during the night was significantly related to self-reported sleep disturbances (Brink, 2011). Considering our findings, the difference in noise patterns found in the noise and the quiet group, as discussed earlier, was the result of an overall interpretation of three noise indicators. As the correlation analyses were performed for each noise indicator separately, the distinctive noise patterns tended to disappear, which might have influenced our results.

In exploring a relationship between reported night noise disturbances (VAS) and sleep outcomes, significant correlations were found in the noise group. They mainly concerned sleep onset latency and sleep quality. These two sleep variables seem to be particular sensitive to noise intrusion, as different studies were able to find a relationship between adverse night noise reactions and sleep disturbances as well (Fyhri and Aasvang, 2010; Jakovljević et al., 2006; Öhrström, 1993; Van Renterghem and Botteldooren, 2012). Most important however, is that reported night noise disturbances are considered as a stress outcome, which is known to affect health and well-being in the long term (Babisch, 2011; Ising and Kruppa, 2004; Lercher, 1996).

4.3. Role of the bedroom location in noise and sleep assessment

Whereas almost no significant differences between inside and outside noise levels with respect to the bedroom location were found in the quiet group, outside noise levels in the noise group were far more elevated for those participants having their bedroom located at the street side. Again, this was not reflected inside the bedroom, where no differences in noise levels were found.

Subjectively, participants in the noise group and sleeping at the street side, reported significantly more noise intrusion from road traffic, but this did not influence their degree of sleepiness in the morning, mood, pre-sleep arousal levels or any sleep variable registered with actigraphy. However, their sleep onset latencies assessed with daily sleep logs, as well as reported in the general questionnaire, were significantly increased.

Although some field studies emphasized on the role of the bedroom location in determining noise induced sleep disturbances (Bluhm et al., 2004; Öhrström, 1993; Paunović et al., 2009; Van Renterghem and Botteldooren, 2012), further research with larger population samples is needed. In our opinion, the bedroom location is not only a major determinant for noise assessment, but also for sleep outcomes. Whether noise induced sleep disturbances and its consequences for health and well-being

only prevail in those persons sleeping at the most exposed façades of their homes cannot be fully confirmed with present findings. Further studies addressing this issue should help in the development of protective and preventive measures against nighttime noise disturbances.

5. Conclusion

In this study, we found that subjects living and sleeping in noisy regions correctly perceive their environment in terms of noise exposure. This is demonstrated by the general questionnaire on road traffic noise disturbances where an overall discomfort due to the noise clearly distinguished them from subjects in quieter regions. Also, in the evaluation of nocturnal noise disturbances, subjects in the noise group reported increased levels of noise intrusion, mostly due to road traffic. Regarding the noise measurements, the inside noise levels did not follow the outside levels, though different noise patterns could be described as characteristic for a noisy and a quiet environment. The impact on sleep, however, was only modest and we did not find any influence of noise intrusion on mood or pre-sleep arousal levels. Considering the subjectively reported noise disturbances during the night, a clear relationship between noise and sleep outcomes could be established; with sleep onset latencies and judged sleep quality being particularly impacted.

We applied a test protocol which allowed gathering as much information as possible in a home situation without interfering with the daily activities of our participants. As none of them dropped out during the test week or formulated any complaint regarding the test protocol, we can conclude that the method used was non-invasive for our subjects.

As only a few field studies in this domain performed actual inside and outside noise registrations, we believe that our findings might lead to the formulation of additional research questions. Our results showed that the noise subjects are directly exposed to during the night might not be described realistically if only averaged outside noise levels are considered. This stresses the importance of assessing inside and outside noise levels as well as the use of multiple noise indicators. Additional emphasis should be put on quiet control regions and the bedroom location, as this can influence noise and sleep outcomes. Collecting daily information on window positioning, as well as subjective noise disturbances during the night might not only provide crucial information on how participants experience and deal with the noise, but also allows for a more qualitative interpretation of the actual noise situation.

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References

Babisch W. Cardiovascular effecs of noise. Noise Health 2011;13:201–4.
Basner M, Müller U, Elmenhorst E. Single and combined effects of air, road and rail traffic noise on sleep and recuperation. Sleep 2011;34(1):11–23.
Belojević G, Jakovljević B, Aleksić O. Subjective reactions to traffic noise with regard to some personality traits. Environ Int 1997;23(2):221–6.
Bluhm G, Nordling E, Berglind N. Road traffic noise and annoyance—an increasing environmental health problem. Noise Health 2004;6(24):43–9.
Brink M. Parameters of well-being and subjective health and their relationship with residential traffic noise exposure—a respresentative evaluation in Switzerland. Environ Int 2011;37:723–33.
Buysse DJ, Reynolds CF, Monk TH, Berman SR, Kupfer DJ. The Pittsburgh Sleep Quality Index: a new instrument for psychiatric practice and research. Psychiatry Res 1989;28:193–213.
Curran SL, Andrykowski MA, Studts JL. Short form of the profile of mood states (POMS-SF). Psychometric information. Psychol Assess 1995;7:80–3.
de Kluizenaar Y, Janssen S, Vos H, Salomons EM, Zhou H, van den Berg F. Road traffic noise and annoyance; a quantification of the effect of quiet side exposure at dwelling. Int J Environ Res Public Health 2013;10:2258–70.
Dratva J, Zemp E, Dietrich D-F, Bridevaux P-O, Rochat T, Schindler C, et al. Impact of raod traffic noise annoyance on health-related quality of life: results from a population-based study. Qual Life Res 2010;19:37–46.
Eberhardt JL, Strâle L-O, Berlin MH. The influence of continuous and intermittent traffic noise on sleep. J Sound Vib 1987;116(3):445–64.
Fyhri A, Aasvang GM. Noise, sleep and poor health: modeling the relationship between road traffic noise and cardiovascular problems. Sci Total Environ 2010;408:4935–43.
Griefahn B, Gros E. Noise and sleep at home, a field study on primary and after-effects. J Sound Vib 1986;105(3):373–83.
Griefahn B, Schuemer-Kohrs A, Schuemer R, Moehler U, Mehnert P. Physiological, subjective and behavioral responses during sleep to noise from rail and road traffic. Noise Health 2000;3(9):59–71.
Guski R, Feldcher-Suhr U, Schuemer R. The concept of noise annoyance: how international experts see it. J Sound Vib 1999;223(4):513–27.
Hoddes E, Zarcone V, Smythe H, Phillips R, Dement WC. Quantification of sleepiness: a new approach. Psychophysiology 1973;10:431–6.
Horne JA, Pankhurst FL, Reyner LA, Hume K, Diamond D. A field study of sleep disturbances: effects of aircraft noise and other factors on 5,742 nights of actimetrically monitored sleep in a large subject sample. Sleep 1994;17(2):146–59.
Ising H, Kruppa B. Health effects caused by noise: evidence in the literature from the past 25 years. Noise Health 2004;6(22):5–13.
Jakovljević B, Belojević G, Paunović K, Stojanov V. Road traffic noise and sleep disturbances in the urban population: cross-sectional study. Croat Med J 2006;47:125–33.
Johns MW. A new method for measuring daytime sleepiness: the Epworth Sleepiness Scale. Sleep 1991;14(6):540–5.
Kohsaka M, Fukuda N, Honma K, Honma S, Morita N. Seasonality in human sleep. Experientia 1992;48(3):231–3.
Lercher P. Environmental noise and health: an integrated research perspective. Environ Int 1996;22(1):117–29.
Lockley W, Skene DJ, Arendt J. Comparison between subjective and actigraphic measurement of sleep and sleep rhythms. J Sleep Res 1999;8:175–83.
Marks A, Griefahn B. Associations between noise sensitivity and sleep, subjectively evaluated sleep quality, annoyance, and performance after exposure to nocturnal traffic noise. Noise Health 2007;9:1–9.
Murphy E, King EA. An assessment of residential exposure to environmental noise at a shipping port. Environ Int 2014;63:207–15.
Muzet A. Environmental noise, sleep and health. Sleep Med Rev 2007;11:135–42.
Nicassio PM, Mendlowitz DR, Fussell JJ, Petras L. The phenomenology of the pre-sleep state: the development of the pre-sleep arousal scale. Behav Res Ther 1985;23(3):263–71.
Nivison ME, Endresen IM. An analysis of relationships among environmental noise, annoyance and sensitivity to noise, and the consequences for health and sleep. J Behav Med 1993;16(3):257–76.
Öhrström E. Sleep disturbance, psycho-social and medical symptoms—a pilot survey among persons exposed to high levels of road traffic noise. J Sound Vib 1989;133(1):117–28.
Öhrström E. Psycho-social effects of traffic noise exposure. J Sound Vib 1991;151(3):513–7.
Öhrström E. Long-term effects in terms of psycho-social well-being, annoyance and sleep disturbance in areas exposed to high levels of road traffic noise. In: Vallet M, editor. Noise and Man '93, Noise as a public health Problem, 2. Proceedings of the 6th International Congres; 1993. p. 209–12.
Öhrström E. Longitudinal surveys on effects of changes in road traffic noise: effects on sleep assessed by general questionnaires and 3-day sleep logs. J Sound Vib 2004a; 276:713–27.
Öhrström E. Longitudinal surveys on effects of changes in road traffic noise—annoyance, activity disturbances, and psycho-social well-being. J Acoust Soc Am 2004b;115(2):719–29.
Öhrström E, Rylander R. Sleep disturbance by road traffic noise—a laboratory study on number of noise events. J Sound Vib 1990;143(1):93–101.
Öhrström E, Skånberg A. Longitudinal surveys on effects of road traffic noise: substudy on sleep assessed by wrist actigraphs and sleep logs. J Sound Vib 2004;272:1097–109.
Ouis D. Annoyance caused by exposure to road traffic noise. An update. Noise Health 2002;4(15):69–79.
Passchier-Vermeer W, Vos H, Janssen SA, Miedema HME. Sleep and traffic noise. TNO-rapport 2007-D-R0012/A Slaap en verkeersgeluid, Delft, NL; 2007.
Paunović K, Jakovljević B, Belojević G. Predictors of noise annoyance in noisy and quiet urban streets. Sci Total Environ 2009;407:3707–11.
Pirrera S, De Valck E, Cluydts R. Nocturnal road traffic noise assessment and sleep research: the usefulness of different timeframes and in- and outdoor noise measurements. Appl Acoust 2011;72:677–83.
Sadeh A. The role and validity of actigraphy in sleep medicine: an update. Sleep Med Rev 2011;15:259–67.
Stansfeld SA, Matheson MP. Noise pollution: non-auditory effects on health. Br Med Bull 2003;68:243–57.
Stošić L, Belojević G, Milutinović S. Effects of traffic noise on sleep in an urban population. Arh Hig Rada Toksikol 2009;60:335–42.
Tulen JHM, Kumar A, Jurriëns AA. Psychophysiological acoustics of indoor sound due to due traffic noise during sleep. J Sound Vib 1986;110(1):129–41.
Tworoger SS, Davis S, Vitiello MV, Lentz MJ, McTiernan A. Factors associated with objective (actigraphic) and subjective sleep quality in young adult women. J Psychosom Res 2005;59(1):11–9.
Urban J, Máca V. Linking traffic noise, noise annoyance and life satisfaction: a case study. Int J Environ Res Public Health 2013;10:1895–915.
Vallet M, Gagneux J-M, Blanchet V, Favre B, Labiale G. Long term sleep disturbance due to traffic noise. J Sound Vib 1983;90(2):173–91.
Van Renterghem T, Botteldooren D. Focused study on the quiet side effect in dwelling highly exposed to road traffic noise. Int J Environ Res Public Health 2012;9:4292–310.
Welch D, Shepherd D, Dirks KN, McBride D, Marsh S. Road traffic noise and health-related quality of life: a cross-sectional study. Noise Health 2013;15:224–30.
World Health Organization (WHO). Night noise guidelines for Europe. Copenhagen: World Health Organisation; 2009.
World Health Organization (WHO). Burden of disease from environmentel noise—quantification of healthy life years lost in Europe. Copenhagen, Denmark: WHO Regional Office for Europe; 2011.